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Design and Engineering of a Theatre Façade in Vlaardingen

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In 2004/2005 a design of a theatre extension in Vlaardingen, ‘de Stadsgehoorzaal’ was made by architect Cees Spanjers, Mick Eekhout and Octatube Engineering. This façade contains the lobby at the first floor. The façade had to obtain a characteristic design in the townscape. The structure of roof and floor in steel enabled the façade to be independent. However, the architect required a solution where the visually lightweight structure would be independent and wrapped around both left and right corner. This wrapping caused interesting problems which were solved by a tubular frame structure on top, bottom and both ends and a fish belly truss at the both corners. In doing so the glass façade could obtain an extreme lightweight composition.

Keywords: tensile stabilization, space frame trusses, diagonal glass panels, climate façade.

1. Introduction

In 2004 Mick Eekhout was approached by architect Cees Spanjers of the office Zaanen Spanjers Architects, Amsterdam, specialist in theatre renovations, to collaborate in a design for an extension of the Vlaardingen theatre from the 1950s. They had worked together in the Glass Music Hall in the Exchange of Berlage (1903) in Amsterdam, in the Nieuwe Kerk (1658) in The Hague. In both occasions the technical design had an important influence of the architecture. The Glass Music Hall was the first pre-stressed glass construction in the Netherlands, built in 1990. The former exchange, where more noise meant more trading deals, was transformed in to a rehearsal hall for the Netherlands Philharmonic Orchestra and a chamber music concert hall. The glass envelope had an acoustical function to separate outside form inside atmosphere. Glass thickness 8mm. All glass panels were suspended from each other, putting the highest glass panels under deadweight of the lower 4 panels. That was the technical leap forward in 1990. It was well documented in a book on the subject: ‘Product Development in Glass Structures’, 1991 [Ref.1]. See figure 1. The glass structure in the Nieuwe Kerk was used to get a shorter reverberation time in this church. The acoustics were very well suited for organ music and multi-vocal psalm singing, but inadequate for chamber music. Hence the echo time had to be shortened dramatically. A ceiling at 10 m height and curving suspended glass panels 10mm thick hanging from 10 m height to

3 m height. The ground floor is uninterrupted. The acoustics improved enormously by this suspended glass box. Because of the waving form of the glass and the dark atmosphere in the church, on photographs the structure is hardly visible. Figure 2. The structure is suspended from 2 tubular arches, resting on the 25 m high brickwork wall.

Figure 1: Outside view of the Glass Music Hall of 1990 designed by Cees Spanjers and Mick Eekhout.

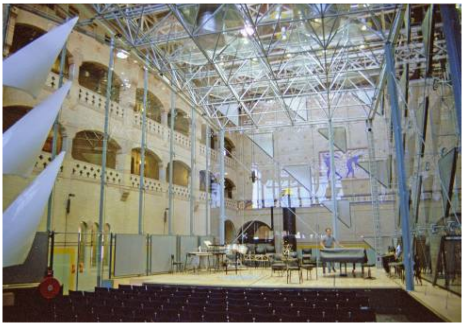


Figure 2: Inside view of the Glass Music Hall of 1990 designed by Cees Spanjers and Mick Eekhout.

Figure 3: interior view of the suspended glass envelope in the Nieuwe Kerk, The Hague.

The collaboration between architect and structural designer had worked before. In Vlaardingen the architect wanted to have a strong visibility of the theatre in the inner city. The former theatre was built backward and the extension would make the theatre visible tangentially along the street. The first floor façade would have to be an independent glass envelope as an entity, a glass block with a surprising and unexpected visual quality in the town of Vlaardingen. For that reason the different building parts had their different characteristics: a solid volume, timber window façade and as the crown of the street appearance, the glass block with the special diagonal bracing. The glass volume had to be placed on the pavement, a bit forward on the street. The real façade would be built slightly backwards compared to the architectural concept.

Technically the façade was a complex artifact, containing a visually minimal steel structure as a glass picture frame all around, with an inner layer of insulated glass panels and an outer layer of single glass panels. All glass panels were designed to be positioned diagonally. This set-up would suffice for the building physical requirements of solar entrance, thermal insulation and sound separation between the street and lobby. The architect envisaged a roof structure in steel supported by steel circular columns, which also carried the first floor structure. The glass structure found its stability and supporting structure in the circular columns.

From the supporting columns initially a framing steel structure around the glass volume was designed. In the transition between the floor and roof an open profile, flanking the roof area would hardly be visible. From there s the studies went into two ways: a diagonal space frame as to accommodate the wish of the architect of 45° angles in the glass inside and outside and a vertical tensile stabilization. The space frame design scheme is given in fig 4.a. However, since the central part of the façade would be provided with a pre-stressed tensile rod system, the pre-stress reaction forces would influence the loading on these open profiles with forces in the cross direction. However, since the two directions of counter stabilising tensile rods are attached to the frame at a distance. The inner stabilisation would be essentially in a cable-form: wind pressure causing an inward curving series of tensile rods and wind suction would cause an outward curving series of tensile rods. If the outward and inward curving series of rods are connected at the perimeter the belly would be large. the cross section would be a ‘lens-form’. The belly is more slender when the two directions of rods cross each other in a kind of ‘fish-form’, half as slender. This were the two choices for the positioning of the tensile rods. Positioning the rods vertical had its simplicity as the system was straight-forward in its cross section. This scheme was extensively studied. See fig. 4b.

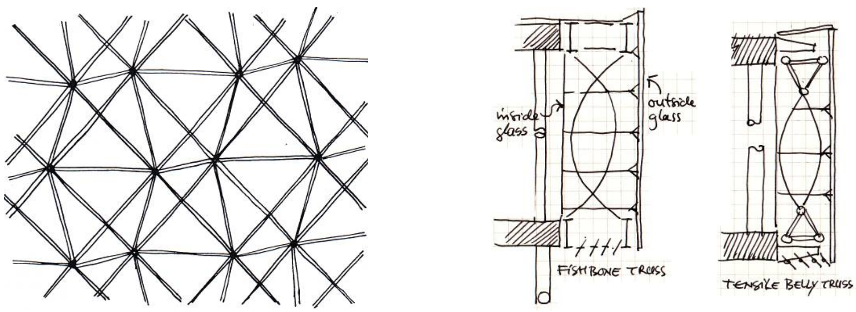


Figure 4: The space frame scheme and the vertical stabilisation in scheme.

The design of the architect for the 1st floor lobby consisted of a tubular column and roof beam structure with diagonally braced glass panels. In this design concept the tensile stabilisation would emphasize the visual lightness of the façade as a plane. The considerations of the edge or beam profiling as a single or double I-profile respectively a triangulated space truss has been considered in relationship with the visual appearance. The project structural engineer was Zonneveld, Rotterdam. The two corner components had as a function to enable the glass façade and its backing stabilisation structure around the corner. Initially they were seen as a CHS profile, a round tube. See fig.5 for design sketches.

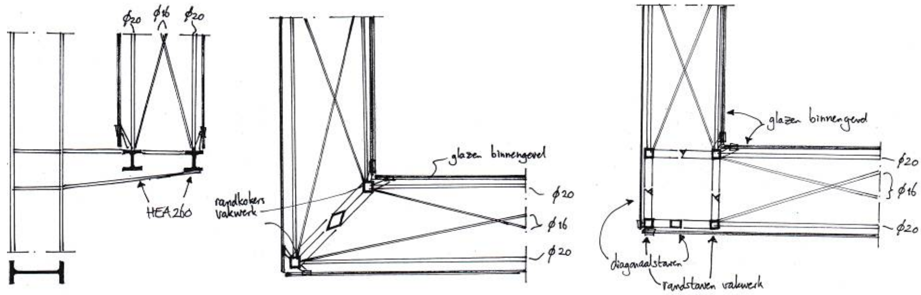


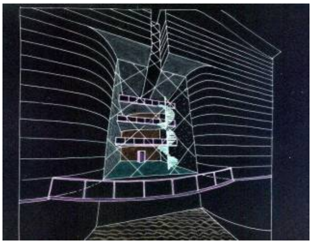
Figure 5: Several vertical and horizontal corner solutions in sketch form.

However the turning of the position of the glass panels 45° as the architect desired, complicated the tensile stabilisation. A vertical stabilisation behind 45° would flow more in the directions of the graphical lining as desired by the architect. It then would be logical to start with the lens-form arrangement, connected to the top tube of the bottom delta truss en to the bottom tube of the top delta truss. The problem came in the corner. The lens-form tensile trusses would be ideally supported under 45° at the corner in horizontal position by an equally lens-shaped tubular truss. The tensile system had been worked out in numerous projects by Octatube as a two-directional system (see fig. 6 and 7). It distributes the loading forces equally to the substructure, in this case the 'encadrement' of the delta trusses around the glass façade.

Figure 6: Two-way stabilised roof structures Droogbak, Amsterdam.

Figure 7: Façade structure Museon, Tel Aviv.

The diagonal turning of the glass panels brought some experiences in the company at two projects: the Antaris office building designed by architect Aad van Tilburg in Hoofddorp (fig 8) and the Glass Music Hall of the Prinsenhof Museum, Delft (fig 9), designed by architect Mick Eekhout. Diagonally positioning the glass panels was found to be extremely vulnerable for positioning of the double glass panels as the panels rest on the 2 lower diagonal sides and the position of the glass panels is hard to shift or slide during assembly and hence the lining of these panels is far more difficult and labor intensive than panels with horizontal lower sides where the supports can be two glass blocks during temporary fixing. The glass façade of the Prinsenhof Hall was built in the winter of 1996/1997; It was the first application of a diagonally positions tensile bracing of a façade of around 8 x 17 m , subdivided in two squares of 4 x 4 panels. In this case the architect, desired a diagonal bracing to have only a minimum of steel structure in view of the façade when looking from the inside outward to an existing gothic church. Also here it appeared that the winter period with temperatures below zero en the queen opening the Hall 2 months later, so with a strong planning of the façade installations, the accuracy of positioning the tensile rods needed to be extremely high. Also here it appeared that the usual shifting or positioning in the horizontal direction separate from the vertical direction, as usually is the case was not possible. Shifting a point in 3D meant that the diagonal shift was both vertical and horizontal at the same time. Panels broke due to the forces on the glass. We had to demount a series of panels and adjust the rods and reinstall.



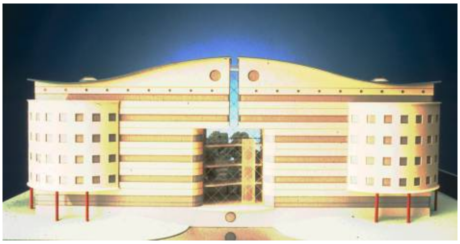


Figure 8: Antaris, Hoofddorp NL diagonal façade.

Figure 9: Prinsenhof Hall, Delft, diagonal bracing.

The knowledge on diagonal bracing had warned Octatube for possible problems and these were incorporated in a new arrangement of rods, the pre-stress possibilities in all rod ends, and connection methods for the glass panels, free to move horizontally independent from vertically.

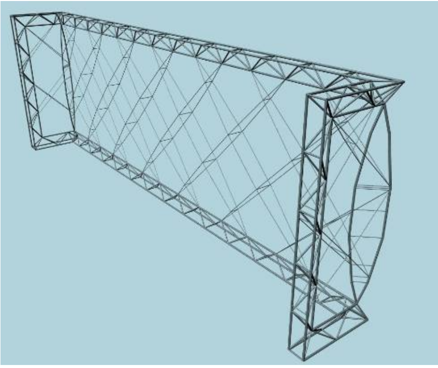


Figure 10: The resulting geometric arrangement as a perspective view.

The glass panels on the outside are single fully tempered glass panels, mechanically fixed by Quattro nodes (see figure 11). The inside panels are insulated glass panels fixed from the outside, the air cavity in fact mechanically, while the inner pane, on the lobby side has been fixed chemically. So the insulated glass panels have been fixed mechanically from one pane while the other pane is fixed by the buthylene sealant of the panel composition.

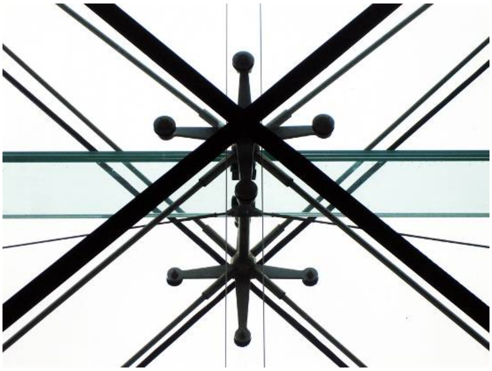


Figure 11: Detail Quattro nodes..

The production and assembly of this façade has been done by BRS, a Dutch supplier. The only deviating detail form the design and engineering drawings are the two outer corners that are covered with a 70 mm wide angle-profile. It would have been much more sensible if the corner would have been a butt joint of the cantilevering outer panels of the corner panels. Another solution would have been to shorten the corner panels with straight package ends and insert a prismatic borosilicate glass rod here in clear glass. Both corners are catching sunlight which would have caused brilliant colour radiations in stead of a corner profile.

Figure 12: Detail of the corner.

The stainless steel components of the tensile rigging system have been detailed in such a way that all rods are adjustable separately, the only correct way to have the complex diagonal braced geometry correctly installed on a fraction of millimetres.

The façade has a height of 5 m. The inside cab be cleaned from a ladder or scaffold; the outside cab be cleaned from a telescopic cherry-picker from the street pavement. The inside volume is more of a problem. On two levels the space between the two façades is provided with laminated glass planks, which span a full 3.3 m, being the horizontal distance between two horizontal Quattro rods. In order to stiffen the triple laminated glass a single vertical strut is positioned under the glass with two sideward tensile rods. The access ladder is positioned sideward. One of the side panels is can be opened for access from the lobby.

The climate system was designed by Peutz Associes, Zoetermeer. In summer and warm hours the lower side ventilator louvers under the canopy part of the façade, the part sticking ouit on the street, can be opened for access of fresh air, which is sucked thought the space between the two glass planes and extracted in the roof level. The façade, although almost exactly positioned on the south, has an agreeable indoor climate as a result.

The main issue for the structure was to design a stable and controlable tension structure, within the given architectural context. The context in this case was far from ideal from a structural point of view. First of all the architect desired a diagonal tension system within two directions. Although this isn't necessarily very complex, it does become complex when those diagonal trusses need to be wrapped around the corners. The other difficulty was the lack of a stiff support structure around the pretensioned facade.

Normally, using a tension truss spanning between two support structures, the support structure needs to be very stiff. In case of unlimited stiffness of the supports the difference between a pretensioned truss is not very different from the same truss without pretension. The structural difference is the fact that in a pretensioned system the vertical forces exerted on the supports stay the same, regardless wether there's a wind load present or not. In the non-tensioned truss, the vertical force on the support is lineair related to the wind load. For flexible supports instead of fixed supports the total deformation of the truss in horizontal direction will be much higher.

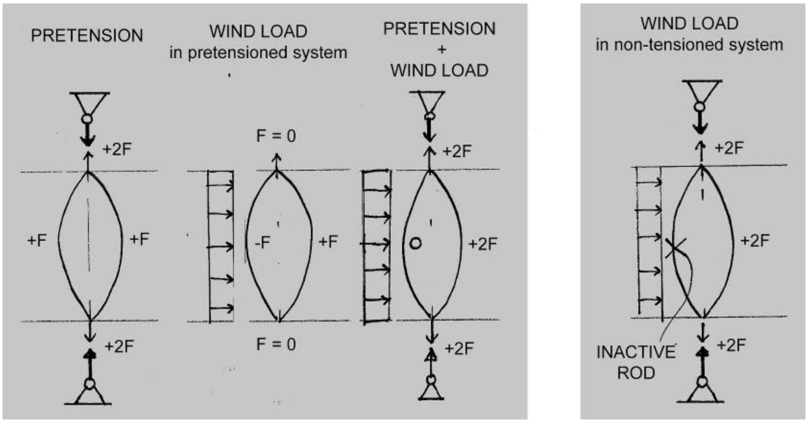


Figure 13: Pretensioned truss with wind load vs. a non-pretensioned tension truss.

Allthough it may appear rather stiff due to its triangulated truss framing the facade, it in fact can be regarded as a very flexible support for the diagonal tension structure. The truss supports are cantilevering from the three main steel columns behind the double layered facade. (See figure 14).

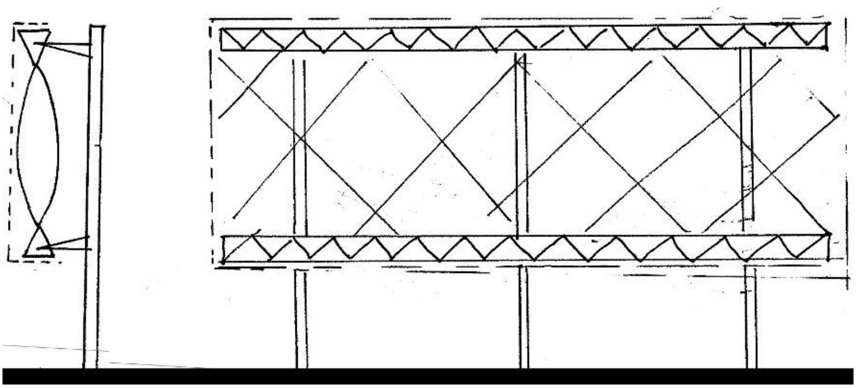


Figure 14: Support structure trusses.

Because the supports for the tension system for the theater of Vlaardingen could be considered very flexible, it was very important to design a controllable pretensioned structure to avoid too large deformations of the facade. Once the pretensioning will be applied, the forces onto support structure of triangular truss, cantilevers and facade columns will only vary a little.

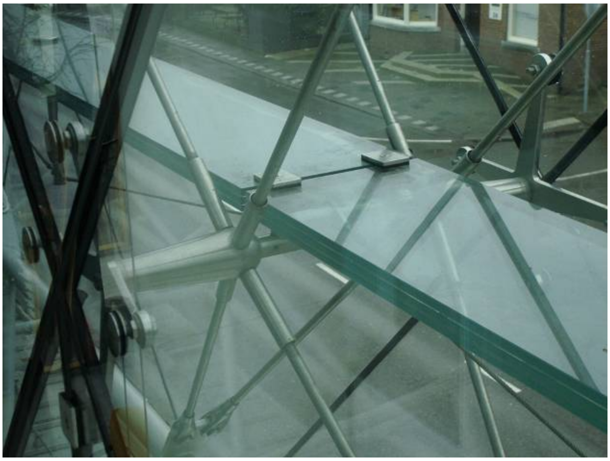


Figure 15: Detail node.

In the structural analysis also the rear structure of the cantilevers and the three columns by others were taken into account as well. Al together the analysis costs a lot of time, especially for determining the pretension force. Because of its flexibility tensioning one rod will have influence on the pretension of all other rods in the face. Therefore applying these forces (even in computer analysis) is comparable to tensioning a bicycle wheel until it is perfectly round. It took many trial and error sessions of running the analysis to achieve a satisfying result.

All of these analysis being more troubled by the wrapping of the tension trusses around the corner. These tension trusses are folded around a lens-shaped steel truss to stay in the same esthetical language, which again added more flexibility and therefore unpredicability to the application of the prestress. All together it is was probably the most complicated way to fit in a prestress facade structure into a building, but is was something to be proud of after it had been proved engineeringswise.

Figure 16: Exterior viewof the façade.

Figure 17: Interior view.

2. Conclusion

The design of the Theatre facades of the Vlaardingen 'Stadsgehoorzaal' was strongly influenced by the desire of the architect to have the plane of the front façade continue over both corners into the side elevation, to have a continuity of the glass planes, to have a diagonal positioning of the glass panels and a double climate facade system. These ingredients were integrated into the composition of the facade construction. The diagonal positioning of the glass panels, the diagonal stabilization by tensile rods, proved a complex matter for the structural engineers and resulted in a n extensive structural analysis report, but all elements had been experienced before at least one time. the proved to be feasible. The design and engineering was done by Octatube. The final production and installation was done by BRS without major alterations. The theatre front elevation has been successfully position by the architect in a far more prominent way in the townscpe of Vlaardingen then ever before.

Figure 18: View of the structure.

3. References

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